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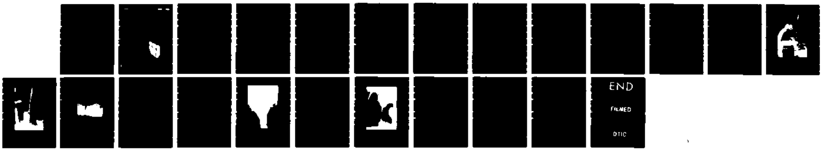

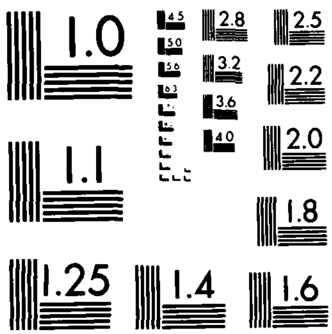

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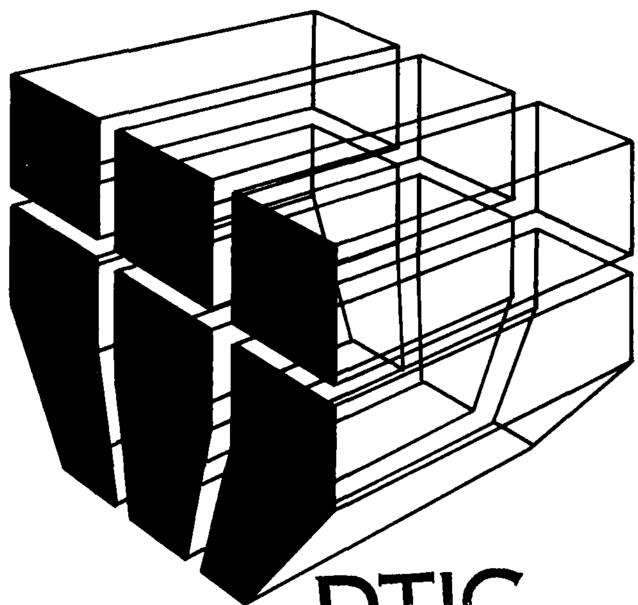
TECHNICAL REPORT M-85/17
June 1985
Foam Structures for Mobilization Facilities

AD-A157 107

Full-Scale Fire Tests of Polyurethane Foam Dome Structures

by
Laura A. Hrdina

This report documents research to determine the behavior and performance of uncoated rigid polyurethane foam (PUF) and of PUF coated with thermal barrier materials in full-scale fires on foam dome structures. Six PUF dome structures were tested for compliance with specified fire criteria and the results evaluated. The research showed that the coated structures complied with specific Department of Defense fire safety criteria, and furthermore that such a coating is necessary to prevent rapid spread of fire. Since the geometry of the test room apparently has no effect on a structure's ignitability or on the spread of fire, it was also concluded that reasonably fire-resistant structures may be built of PUF for *housing during mobilization.*



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FOREWORD

This investigation was conducted for the Installation and Planning Division, Office of the Assistant Chief of Engineers (OACE), under RDT&E program 6.27.31A, Project 4A162731AT41, "Military Facilities Engineering Technology"; Task A, "Facility Planning and Design"; Work Unit 066, "Foam Structures for Mobilization Facilities." The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL) under the supervision of the National Bureau of Standards representatives. The information on the fire tests was provided by the National Bureau of Standards. The OACE Technical Monitor was LTC D. Ghiglio, DAEN-ZCI-A.

Dr. R. Quattrone is Chief of USA-CERL-EM. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

FULL-SCALE FIRE TESTS OF POLYURETHANE FOAM DOME STRUCTURES

1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has proposed the use of polyurethane foam (PUF) dome structures for rapid field construction such as housing and other facilities during mobilization. Dome structures allow quick assembly of large, temporary housing made of unreinforced foam. For fire and toxicity safety reasons, building codes and Army specifications forbid the use of plastic foam materials as the sole interior finish surface of residential housing or other occupied structures. However, plastic foam may be used if its flame spread index is limited and if it is protected by a suitable thermal barrier. Therefore, before its use in such structures, the fire and toxicity issues associated with PUF must be investigated.

The toxicity issue has been resolved satisfactorily. An investigation[1] showed that carbon monoxide is the primary toxic product of PUF combustion. A toxicity screening test indicated that rigid foam is safer than Douglas fir, red oak, and hardboard, among others.[2] Another study showed that burning rigid foam creates the same toxicity hazard as burning the white pine.[3]

For fire safety, the Department of Defense approves[4] the use of foamed (cellular) plastic insulation in residential structures, provided:

1. It meets the criteria of flame spread rating of not greater than 75 and smoke generation of not more than 450 when tested in accordance with American Society for Testing and Materials (ASTM) E-84, "Test for Surface Burning Characteristics of Building Materials." (ASTM E-84 is used to determine the relative burning behavior of the material by observing the flame spread along the specimen.)

2. It is protected by a thermal barrier material equivalent to (or better than) 1/2 in. (12.7 mm) of Type X gypsum board placed between the foam plastic and the interior living space.

Spray-applied PUF formulations are available that meet the required flame spread rating and smoke generation criteria. Manufacturers/suppliers of these products have had them tested by qualified independent test laboratories and can provide letters of certification and compliance.

Fire-resistant thermal barrier coatings are also available which have been tested by independent laboratories and approved by the model building code organizations for use on the qualified foamed plastics insulation.[5] The coatings are applied directly to the foamed plastic surface where they remain in intimate contact with the foam during the service life or test period.

The Army has selected a polyurethane foam of class B material (flame spread of 75 or less when tested in accordance with the ASTM E-84). The foam, protected with five different thermal barriers, has been successfully fire-tested in rooms where the foam lined the walls and ceilings. In those tests a 30-lb (12-kg) wood crib in one rear corner was the ignition source. However, the results had to be verified for full-size structures in which size, configuration, and ventilation conditions differ considerably. Therefore, USA-CERL made plans to conduct similar fire tests in 28-ft (8.5-m)-diameter dome structures. USA-CERL requested the Center for Fire Research at the National Bureau of Standards to help design, instrument, and conduct these tests and to analyze the results.

Objective

The objective of this study was to determine the behavior and performance of uncoated rigid PUF and of PUF coated with thermal barrier materials in full-scale fires on foam dome structures.

Approach

Six PUF dome structures (five with coatings, one without coating) were tested for their compliance with

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[1] Judith A. Dudeck, *Flammability/Toxic Gas Analysis*, Final Report (U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, April 1983).

[2] C. J. Hilado, "Carbon Monoxide as the Principal Intoxicant in the Pyrolysis Gases From Materials," *Journal of Construction Toxicology*, Vol 6 (August 1979), pp 177-184.

[3] K. Sumi and Y. Tsuchiya, "Combustion Products of Polymeric Materials Containing Nitrogen in Their Chemical Structure," *J. Fire and Flammability*, Vol 4, No. 15 (1973).

[4] DOD 4270.1-M, *Construction Criteria* (Department of Defense, December 15, 1983).

[5] Urethane Foam Contractor's Association, *Thermal Barrier Code Approvals, Position Statement* (February 1984).

specified fire safety criteria. The test results were recorded, analyzed, and evaluated, and judgments regarding the use of PUF for rapid construction were made based on the information gained.

Mode of Technology Transfer

It is recommended that the data in this report be used to develop drawings, specifications, and a technical manual for constructing foam dome mobilization facilities.

2 TEST COMPONENTS AND METHODS

Tests of uncoated foam and foam coated with various materials complying with corner test criteria* were conducted to determine two factors:

1. The effects of the test "room's" geometry on the ignitability and spread of fire from a standardized source.

2. Whether reasonably fire-resistive, dome-shaped housing structures can be built with either PUF or a combination of PUF and a coating that makes the PUF resistant to ignition, surface flame spread, and thermal decomposition within a 15-minute test period.

Six hemispherical polyurethane foam structures, each 28 ft (8.4 m) in diameter and nominally 5 in. (101.6 mm) thick with a density of 2.5 lb/cu ft (40 kg m^3) were foamed in place for the fire tests at a site near Danville, IL, during July 1984. Five of the domes had fire-protective coatings (or coverings) on the interior surfaces. Figures 1 and 2 show the location of the instrumentation and the fire source.

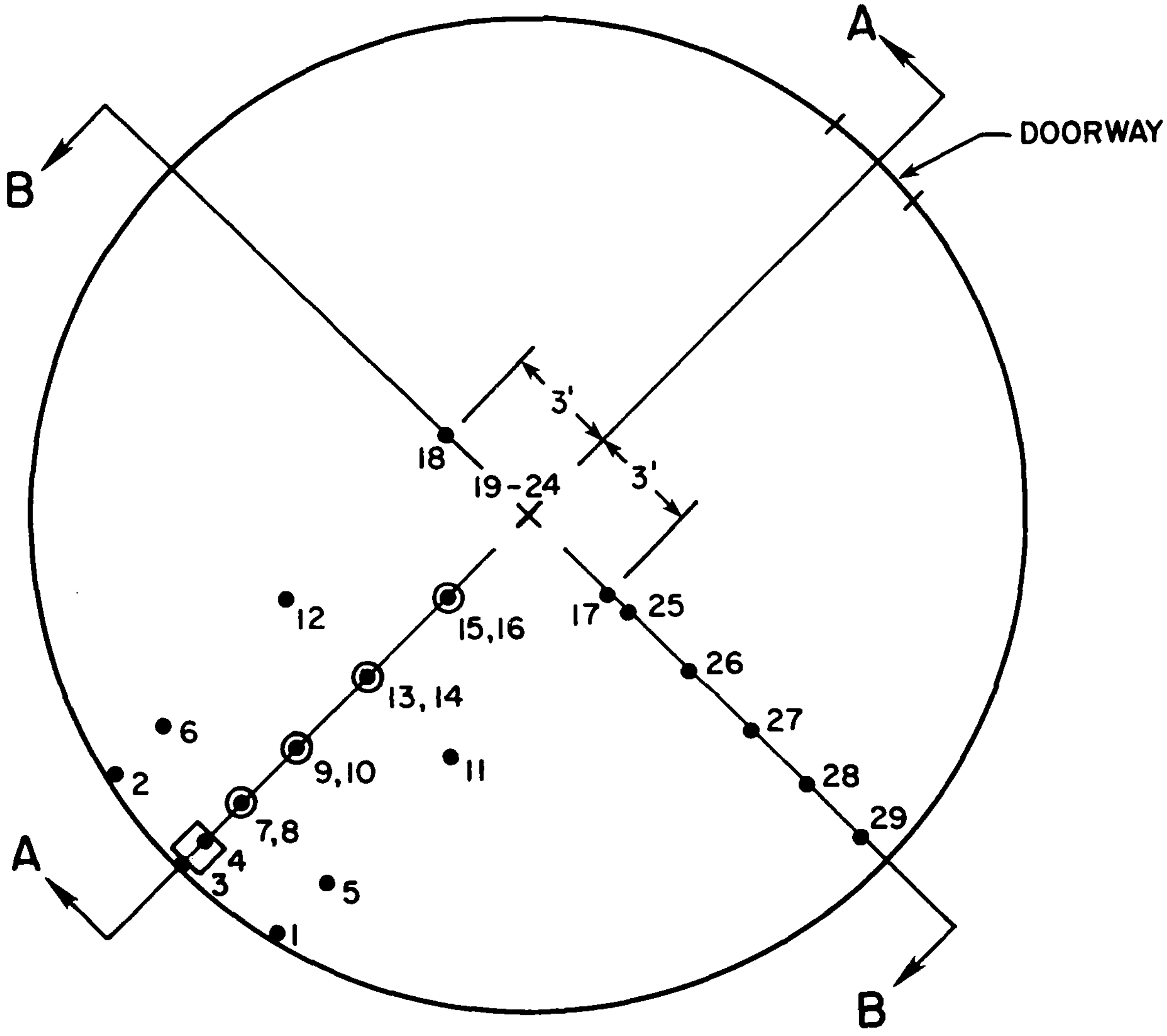
Each dome had a 36- X 80-in. (914.4- X 2032-mm)-high doorway and an 8-in. (203.2-mm) diameter and 12-in. (304.8-mm)-long vent at the top of the structure. Normally, the dome has a ventilator on its top instead of the vent, which was used to allow an unobstructed path for measuring temperatures and flow, if needed.

*In "corner tests," the test materials comprise the surface of two walls and a ceiling juncture, with the size of the test area dependent on the building's intended use. The test representative of residential uses in an 8- × 12-ft (2.4- × 3.7-m) room with an 8-ft- (2.4-m)-high ceiling. The test wall sections and ceiling sections are 8 ft (2.4 m) long from the test corner.

The ignition sources used in the corner tests represent the size of the initial fire which might be typical in an actual structure. The residential corner test requires a 30-lb (13.6-kg) crib of white fir which is predried and contains less than 8 percent moisture to be arranged in a specific manner. The crib for these tests was in an arrangement of 1.5- X 1.5- X 15-in. (38.1- X 38.1- X 381-mm) sticks with five sticks per layer and a total of 11 layers. The crib was placed on 2.3-in. (58.4-mm) bricks on a sheet of asbestos cement board, 36 X 36 X 0.25 in. (914 X 914 X 6.4 mm) thick, placed level on the ground. Overall dimensions of the crib were 15 X 15 X 19.3 in. (381 X 381 X 490 mm) high. The crib was placed as close as possible to the wall opposite the open doorway. However, since the thermocouple support rack was adjacent to the wall, it was not possible to get closer than 3.5 to 6.5 in. (89 to 165 mm) to the wall. In test 1, the crib was inadvertently placed 14.5 in. (368 mm) from the wall. In each case, the crib was ignited by a fire started in 1 lb (0.4 kg) of fluffed wood excelsior soaked with 4 oz (0.1 kg) of absolute ethanol.

The time of the tests begins with the ignition of the fire source and is concluded when the source burns out or after 15 minutes, whichever occurs first. The fire is extinguished at the end of the test period if it has not already burned out.

An array of type K surface thermocouples was used to indicate the degree of surface flame spread. The thermocouples were placed 1 in. (25.4 mm) from the surface and directly over several selected surface thermocouple locations. They measured the temperatures of the hot combustion gases and air at 1 to 3 in. (25.4 to 76.2 mm) from the exposed surface of the test coating along the dome's interior surface. Thermocouples were also used to monitor the downward movement of the hot gaseous layer at the central portion of the dome. Additional thermocouples were used in the dome with the unprotected polyurethane (test 6) to measure surface flame spread along one side of the dome interior. All thermocouples used in this series of tests were 20-gage AWG type K (chromelalumel) with ceramic fiber insulation. All thermocouple measurements were monitored at 10-second intervals with an Autodata recording system and, as backup, at 30-second intervals with a multiple-point chart recorder. Videotape and still photographic documentation was made in every test. No efforts other than a visual observation were made to analyze smoke and the gaseous products of combustion because of the difficulties of making field measurements and in relating these data to actual fire situations.



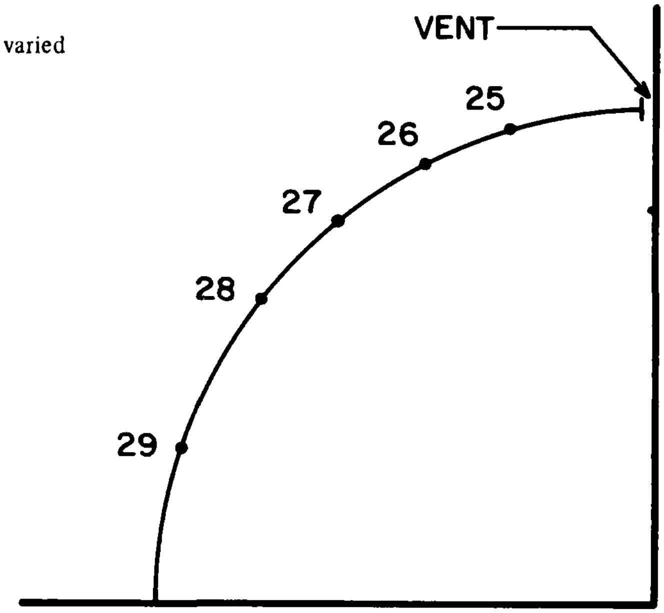
Notes:

Instrumentation along section B-B used only for test 6.

- • Surface thermocouple
- o Thermocouple 1 in. over surface thermocouple to measure air temperature
- x Centerline post with six thermocouples.

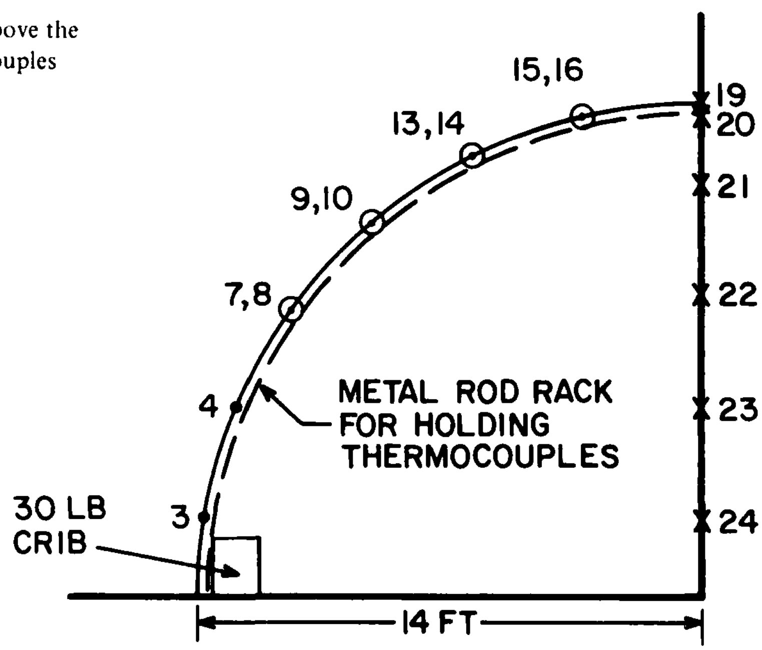
Figure 1. Dome test layout and instrumentation.

Thermocouples 25 through 29 varied from 2.5 to 4.5 ft. apart.
Scale: ⟵5 FT⟶



Section B-B

Thermocouple 3 was 2 ft above the floor. Subsequent thermocouples were about 3 ft apart.
Scale: ⟵5 FT⟶



Section A-A

Figure 2. Sectional views of instrumentation layout. (Metric conversion factors: 1 ft = .3 m; 1 lb = .4 kg.)

To be approved as a thermal barrier material for foamed plastics, the barrier must (1) prevent obvious involvement of the foamed plastic in the fire as indicated by flame spread rating and (2) prevent extensive burning along the surface or flashover while remaining essentially intact. Destruction of the coating and limited burning of the foam immediately behind or adjacent to the fire source and on the ceiling directly over the fire source are acceptable.

DOD 4270.1-M also allows the use of thermal barrier coatings that have undergone other "diversified" tests when corner tests are not appropriate. Therefore, since foam dome structures do not have corners, testing of thermal barrier coatings applied to PUF was done to approximate the conditions of a "corner test" for residential structures as closely as possible. Figures 3, 4, and 5 show the test setup.

3 PUF TESTS

Of the six hemispherical PUF dome structures tested, one was bare and five had coatings.

The five coatings tested were:

1. 1-in. (25.4-mm)-thick concrete, fiber-reinforced

2. 0.75-in. (19-mm)-thick Structolite Gypsum Plaster

3. 0.75-in. (19-mm)-thick Zonolite 3300

4. 0.25-in. (6.4-mm)-thick Pyrocrete LD

5. 0.125-in. (3.2-mm)-thick Staytex 4119A.

The domes had one doorway and one vent. The fire initiation source was placed as close as possible to the wall opposite the open doorway.

The fire tests were conducted by the National Bureau of Standards (NBS). The NBS representative was present during all tests and documented the test results independent of influence by any other involved party (i.e., USA-CERL, material suppliers, other observers).

The NBS representative also coordinated the data acquisition. Operation of chart recorders, placement of thermocouples, videotaping, still photography, and other procedures were done by qualified personnel under the direction of the NBS representative.

Table 1 shows the sequence of tests and the thermal barrier materials selected. Of the five test domes with protective coatings, only the Pyrocrete had adhesion problems. In this case, about 30 sq ft (2.7 m^2) of the coating fell off near the top of the dome before testing began; however, the portion of the coating that remained appeared to have good adhesion. The Zonolite coating was friable, and the Structolite lacked the hard, tough surface of the concrete and Staytex coatings. All tests for coated domes began with the ignition of the wood crib and ended when the fire posed an imminent danger to the surroundings or after 15 minutes, whichever occurred first.

Tests were conducted between 17 and 19 July 1984; Tables 1 and 2 summarize the results. Table 2 gives temperature data from both the Autodata and chart recorders. Differences between temperatures measured with the two recorders are due to their different recording intervals, with the Autodata recorder having the better time resolution. Only test 6 had extensive fire involvement of the dome interior surface. Neither surface ignition nor flame spread was observed for tests 1 through 4. Only localized fire involvement occurred in test 5. Consequently, temperature measurements on the dome interior surface were not as useful as those for the hot air and combustion gases (thermocouples 8, 10, 14, and 16) for characterizing fires in tests 1 through 5. In particular, the air temperature near the vent (thermocouple 19) would be the most representative of the upper dome environment because the air and hot combustion gases in the dome became better mixed at that point. Thus, surface temperatures have not been given in the tables except when a value represents the maximum temperature occurring in the fire.

Although the distance separating the crib from the wall ranged from 3.9 to 14.5 in. (99 to 368 mm) for tests 1 through 4, the flame heights were all observed to be about 6 ft (1.8 m) from the floor, and flames from the burning crib impinged at about the same location on the dome surface for each test. Post-test observations indicated that the soot-covered surface areas in those tests were all similar in pattern and size. Comparison of the data in Table 1 also showed that the peak air temperatures near the vent (thermocouple 19) were about the same for all four tests. Examination of the foam in the flame impingement zone behind the coating showed that the foam surface was altered only in test 4. Thermal expansion of the coating and

Figure 3. One pound (0.4 kg) of fluffed wood excelsior soaked with 4 oz (0.1 kg) of absolute ethanol.

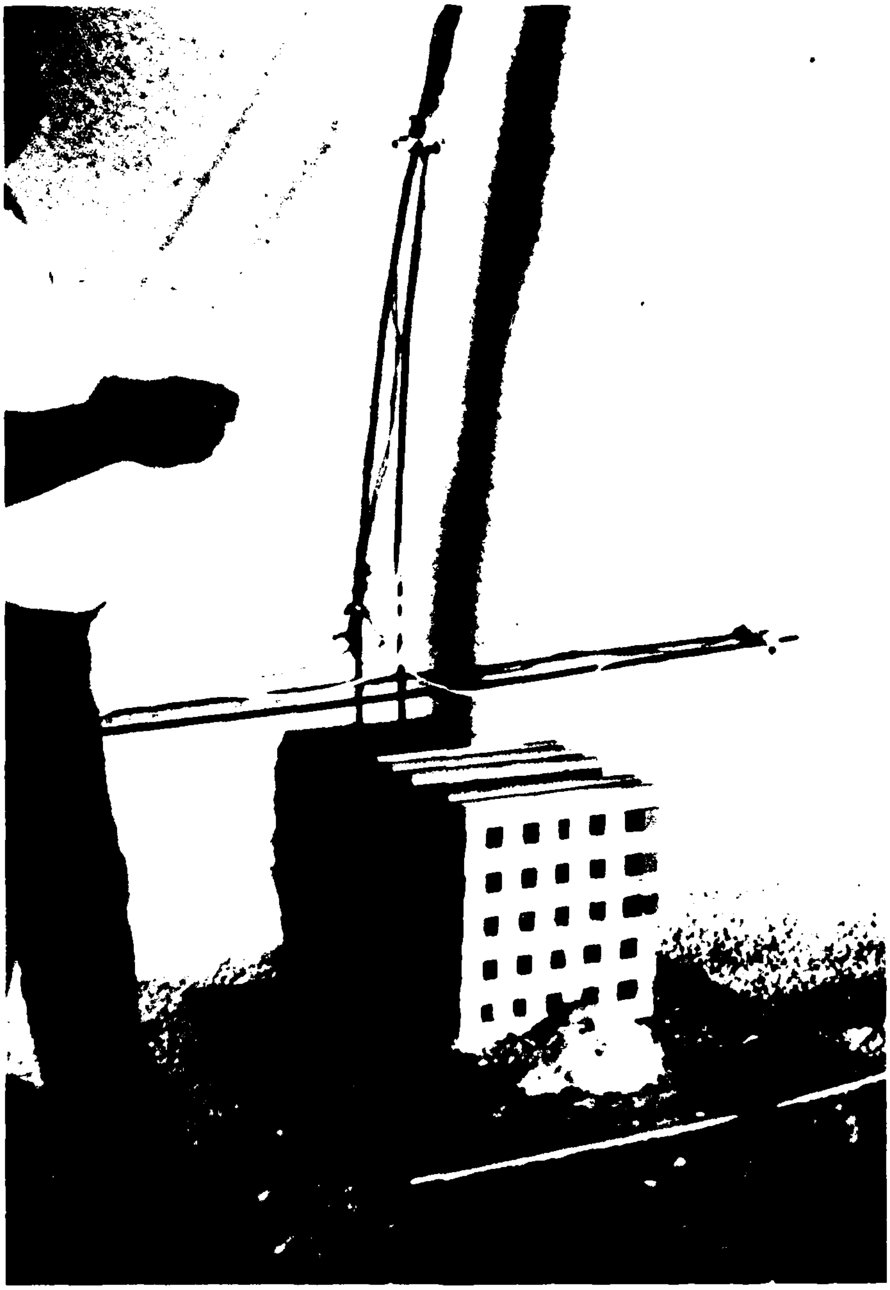


Figure 4. Thirty-pound (13.6) rick of white fir arranged on top of wood excelsior.

Figure 5. View of the fire initiation source placed 1 to 2 in. (25.4 to 50.8 mm) from the wall opposite the open doorway.

presumed outgassing of the foam and coating may have caused the coating to pull away from its substrate in that test, resulting in fine cracks on the foam surface. The Staytex (test 5), which had the thinnest coating of 0.125 in. (3.2 mm), experienced destruction of the coating behind the crib and in the lower part of the crib flame impingement zone (see Figure 6). (As previously mentioned, destruction of the coating is acceptable according to the test criteria.) The foam was heavily charred in this region. Surrounding this entire charred zone and extending farther up along the flame impingement zone, outgassing from the coating and foam apparently caused the coating to separate from the foam substrate. However, there was no fire involvement of the coating or foam beyond this region, other than a small localized blistering of the coating near the front upper part of the dome's interior surface. Table 1 shows that more smoke was observed in test 5 and that the vent air temperature from that test was about 50 C higher than for tests 1 through 4. More smoke was produced in test 5 than in tests 1–4, because a small amount of the foam became involved in the fire.

Results of the first several minutes from test 6 were much like those of the other tests, however, at about 6 minutes, flames began to spread beyond the flame impingement zone. By 8.5 minutes, flames covered

Table 1

Test Parameters and Results

Test	Date	Coating	Distance of Wood Crib From Wall (in.)	Maximum Vent Temp. (°C)	Test Duration (min)	Degree of Fire Involvement
1	July 17	1-in. Concrete, Fiber Reinforced	14.5	145	15	No surface ignition. No flame spread.
2	July 17	0.75-in. Structolite Gypsum Plaster	5.3	153	15	No surface ignition. No flame spread
3	July 18	0.75-in. Zonolite 3300	6.5	140	15	No surface ignition. No flame spread
4	July 18	0.25-in. Pyrocrete LD	3.9	149	15	No surface ignition. No flame spread. Fine surface cracks in foam behind coating in flame impingement zone.
5	July 19	0.125-in. Staytex 4119A	3.5	204	15	Destruction of coating, with burning of foam in 1-ft (.3-m)-wide and 3-ft (.9-m)-high area behind crib and behind lower part of flame impingement zone. No flame spread beyond this region. More smoke production than in tests 1 through 4.
6	July 19	None	3.5	875	9	Fire involvement of the entire interior surface. Heavy production of smoke.

much of the interior surface and came out of the doorway along with dark clouds of smoke. Figure 7 shows that by 8.7 minutes, the interior air temperatures along the entire height of the dome exceeded 700°C. (For comparison, temperatures at similar locations are also shown for tests 1 through 4.) Shortly thereafter, a 15-ft (4.5-m)-long fire plume projected from the doorway and was blown by the wind toward the right side of the dome exterior. The peak total rate of heat release occurred at about this time and probably exceeded 0.5 million Btu/min. (This number is based on a visual estimate of the volume of flaming compared to fire tests in full-size rooms where the heat output was measured.) This value can be compared to an average rate of about 5000 Btu/min for tests 1 through 5 based on a weight loss of about 11 lb (4.4 kg) over a 15-minute duration and assuming a net heat of combustion of 6500 Btu/lb for wood. The intense convective and radiative heat from the plume in test 6 severely burned and charred the exterior surface to the right of the doorway. Post-test observations indicated that more than 100 sq ft (9 m^2) of the dome's exterior was charred with a burn-through at about 1.5 ft (.45 m) to the right of the doorway. Although the dome's exterior surface supported combustion under the severe fire exposure in test 6, a fire test with the dome structure that remained from test 3 showed that the exterior would not support flame spread under modest fire exposures. In this latter test, a bale of dry straw was piled up against the upwind side of the dome and ignited with a match. The foam burned and charred only in the vicinity of the burning straw and, except at the base of the dome, self-extinguished when the active burning in the straw subsided after about 3 minutes. The straw and foam continued to smoulder at the base of the structure, and this smouldering was extinguished after about 30 minutes. A small area (about 4 sq ft [0.36 m^2]) of the foam was charred through to the interior coating.

Figure 7 shows a temperature vs. time graph for thermocouples 19, 22, and 24. (Figure 2 provided

Table 2

Recorded Temperatures

Test No.	Thermocouple No.	Maximum Temperature (Chart Recorder) (°C)	Maximum Temperature (Autodata) (°C)	Time of Occurrence (min)
1	19	145	- *	14.3
	16	171	-	14.9
	14	188	-	13.5
	10	198	-	13.3
	8	248	-	9.2
	4**	302	-	13.1
2	19	153	157	14.8
	16	168	174	14.8
	14	193	200	14.7
	10	233	242	14.3
	8**	356	396	14.7
3	19	140	148	15.0
	16	157	167	15.0
	14	177	188	15.0
	10	207	213	14.8
	8**	263	273	14.2
4	19	149	156	14.7
	16	170	175	14.7
	14	190	191	14.3
	10	199	206	14.8
	8	276	282	14.3
	3**	333	346	10.8
5	19	204	225	14.7
	16	256	381	14.2
	14	285	306	14.2
	10	345	380	14.2
	8	428	490	14.0
	3**	775	794	14.7
6	19	- ***	875	8.5
	16	-	897	8.7
	14	-	800	8.7
	10	-	940	8.7
	8	-	917	8.7
	21**	-	1002	8.7

*Not available due to malfunction of Autodata.

**Thermocouple location where maximum temperature was measured inside dome.

***Chart recorder too slow to record values.

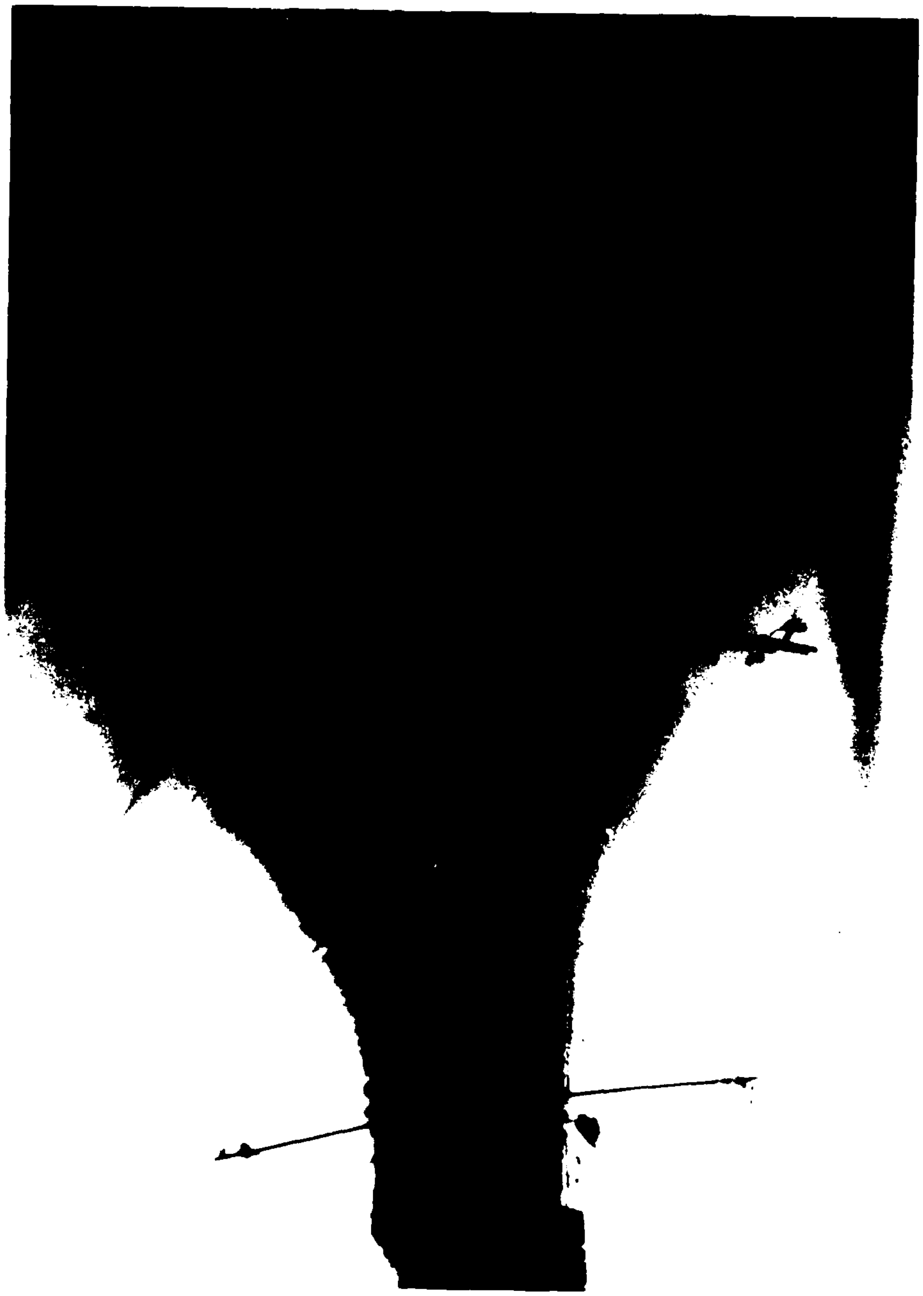


Figure 6. Destruction of the Staytex 4119A coating behind the crib and lower part of the flame impingement zone.

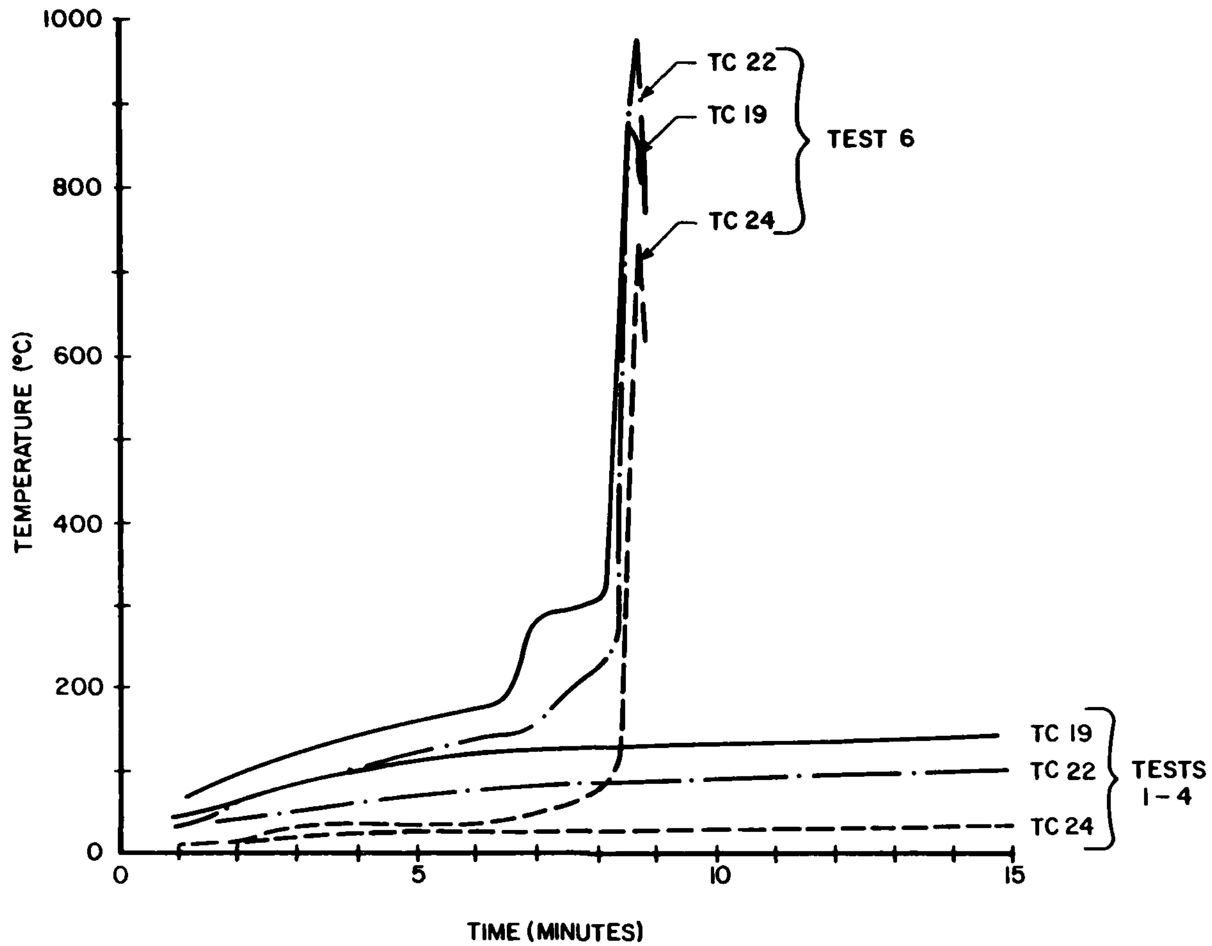


Figure 7. Interior air temperatures along centerline post.

sectional views of the instrumentation layout.) In tests 1 through 4, the temperatures at thermocouples 19, 22, and 24 remained constant. Section A-A of Figure 2 shows thermocouples 19 through 24 located at the center of the dome. Thermocouples 20 through 24 are spaced about 3 ft (0.9 m) apart, with thermocouple 24 closest to the floor of the dome. Thermocouples 19 and 20 are spaced about 3 in. (76.2 mm) apart, with 19 being closest to the interior side of the dome. The maximum temperature (about 150°C) was recorded at thermocouple 19, and the minimum temperature (about 30°C) at thermocouple 24. The maximum temperature in tests 1 through 4 occurred at the top of the dome, implying that in case of a fire, one could avoid higher temperatures by staying close to the floor of the dome.

The smoke produced in tests 1 through 4 was only from combustion of the wood crib. The crib was only partially consumed by the fire in tests 1 through 5, with about 19 lb (8.62 kg) remaining, on the average, at the end of each 15-min test. Figure 8 shows a photograph of the coatings used in tests 1, 2, and 3 after the fire test.

4 CONCLUSIONS

All five coatings tested passed the criteria set forth in DOD 4270.1-M.

The fire test of the uncoated foam dome justifies the need for thermal barriers.

The gemoetry of the test "room" apparently had no effect on the ignitability and spread of fire from a

Figure 8. Photograph representative of coatings that suffered no surface ignition or flame spread.

standardized source in the domes coated with a thermal barrier.

Generally, reasonably fire-resistant, dome-shaped housing structures can be built using a combination of PUF and thermal barrier coatings to make the PUF resistant to ignition, surface flame spread, and thermal decomposition for 15 minutes, provided that the thermal barrier has passed the corner room test and is approved by the model building code organizations.

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